SHEAR STRENGTH OF REINFORCED CONCRETE BEAMS STRENGTHENED WITH EXTERNAL REINFORCEMENT

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APPROVAL SHEET

This project report attached hereto, entitled "Shear Strength of Reinforced Concrete Beams Strengthened with External Reinforcement," prepared and submitted by Alex Tiong Mee Kuei in partial fulfillment of the requirement for the degree of Bachelor of Engineering (CIVIL) is hereby accepted.

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To the mighty God, without Whose strength and wisdom this project could not have been finished.

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ABSTRACT

This thesis presents a study of shear strength of reinforced concrete beams strengthened with external reinforcement. The purpose of this study is to build a model using Strut-and-Tie method to calculate shear strength of reinforced concrete beams strengthened with external reinforcement. An analytical model was proposed for a simply supported beam, externally reinforced with steel plate subjected to a concentrated load at third point of the span. Four modes of failure are identified: two flexural-type failures, namely yielding of internal longitudinal steel reinforcement and yielding of the external steel plate; two shear-type failures namely crushing of a diagonal concrete compressive strut and yielding of shear reinforcement.

ABSTRAK

Tesis ini mempersembahkan pengajian tentang kekuatan ricih untuk rasuk konkrit bertetulang yang diperkuatkan dengan menggunakan plat keluli luaran. Pengajian ini adalah bertujuan membina satu model dengan menggunakan cara "topeng-dan-ikatan" untuk mengira kekuatan ricih rasuk konkrit bertetulang tersebut. Satu model yang bersifat analitik adalah untuk rasuk sokongan mudah, di mana ia dikenakan dengan daya tumpu pada "third-point" rasuk tersebut. Empat jenis kegagalan iaitu dua jenis kegagalan dalam bentuk lenturan; alahan tetulang keluli memanjang dalaman dan alahan plat keluli luaran. Dua jenis lagi kegagalan dalam bentuk ricih iaitu hancuran pepenjuru konkrit mampatan dan alahan tetulang ricih.

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Definition for variables used

a = shear span

L = length of beam

A_s = area of internal longitudinal reinforcement in tension

A'_s = area of internal longitudinal reinforcement in compression

A_{se} = area of external reinforcement

A_{sv} = area of web reinforcement within a distance of ($h' = h/2$) from applied load

b = web width

c = width of diagonal compressive strut at upper node

c' = equivalent width of diagonal compressive strut

c_o = width of horizontal compressive strut at upper node

C = force in diagonal compressive strut

C_o = force in horizontal compressive strut

d_i = effective depth of the internal longitudinal reinforcement in tension (bottom bar)

d' = effective depth of the internal longitudinal reinforcement in compression (top bar)

d_e = depth of external reinforcement

f'_c = concrete cylinder compressive strength

f_{cu} = characteristic cube strength of concrete

f_y = yield strength of internal longitudinal reinforcement

f_{ye} = yield strength of external reinforcement

f_{yv} = yield strength of web reinforcement

F = force in external reinforcement

H, h = beam depth

$h' = d_i - c_o$

P = applied load

s = spacing of web reinforcement (vertical stirrups)

T_1, T_o = force in tension ties formed by internal longitudinal reinforcement

T_s = force in vertical tension tie formed by internal longitudinal reinforcement

V_{ci} = shear resistance to flexure-shear cracking

w = loading platen width

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Structural repair of reinforced concrete (RC) structures is becoming an increasingly important option for all deteriorated constructed facilities in Malaysia. Challenging task confronting structural engineers in the revival of the existing structure is the rehabilitation of concrete structures. Apart from deterioration and aging of concrete structures, other reasons for beam strengthening include upgrading of design code, design errors, change in the use of the structure and overloading. Turkstra (1970) presented structural design, as a problem of a wide variety of circumstances, rational in decision-making is possible although lacking of adequate information. It can be postulated that there exists solution to almost any problem. But the task is to obtain the best solution. Almost in every where and everyday structural engineering usually means a design that minimizes the cost of construction while achieving adequate strength that produces an optimal design.

Most failure in structures occur under loadings that they should have been able to withstand, in this case a human error is indicated, or in other words, under exceptionally high loads which engineers could not expect to happen. Thus a failure in structures is a priority assigned to human error. In periods of high economic activity, there is rapid production of structures; often a new design is designed by engineers with less experience. Following that, structural reliability becomes a matter of concern. In time of low economic activity, on the other hand, existing building or structure present an ever-increasing maintenance problem. In fact, most structures will not fail; they just become a maintenance liability.

Normally the repair or rehabilitation of the existing building is carried out by bonding steel plate or external tendons to the beam. It is a general perception that the more amount of external reinforcement provides more strength to the beam. However, this is not always true, without realizing that before the beam achieves the ultimate flexural strength, the beam has already failed in the shear. Therefore, structural or design engineer should consider the maximum amount of external reinforcement for flexural strengthening of beams which will ensure safety in shear.

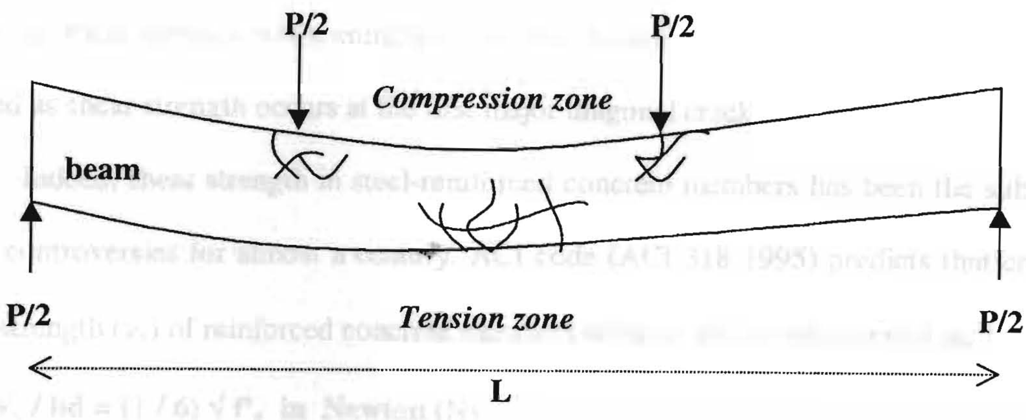

Fig. 1 Simply supported beam subjected to third point loading

1.2 Shear Strength

Shear failures in concrete member are diagonal tension phenomena. For inclined plane the failures are due to combined effect of shear and flexural stresses. As the distribution of shear and flexural stresses over a cross section is uncertain due to the fact that reinforced concrete is a composite, nonhomogeneous, and nonisotropic material that cracks significantly under relatively low loads, it is difficult to determine the value of the diagonal tension stress in a reinforced concrete beam. Basically, prediction of shear strength in reinforced concrete members is an empirical problem based on the assumption that a shear failure at the critical section occurs on a vertical plane when the fictitious shear stress section, V/bd exceeds the concrete fictitious vertical shear strength (also known as nominal shear strength). Generally, there are two definitions for nominal shear strength. The ultimate shear strength, V_u/bd and cracking shear strength V_c/bd. Ultimate shear strength is known as shear strength when complete and total failure occurs while cracking strength is defined as shear strength occurs at the first major diagonal crack.

Indeed, shear strength in steel-reinforced concrete members has been the subject of many controversies for almost a century. ACI code (ACI 318 1995) predicts that cracking shear strength (v_c) of reinforced concrete members without web reinforcement as:

$$v_c = V_c / bd = (1/6)\sqrt{f'_c} \text{ in Newton (N)} \qquad (1.1)$$

Some researchers (Kani 1967; Zsutty 1968; Mphonde and Frantz 1984; Ahmad et al. 1986; Elzanaty et al. 1986; Sarsam and Al-Musawi 1992) had found that shear strength as given in Eq.(1.1) has some imperfection in the prediction. Nevertheless, it has been widely believed, since 1950s, that $\sqrt{f'_c}$ is an adequate predictor of the shear strength of concrete. Accordingly, the ACI building code (ACI 318 1995) has permitted the adoption of design equations in which $\sqrt{f'_c}$ is essentially the main variable controlling the shear strength of concrete. The simplified ACI equation that predicts the cracking shear strength equation for reinforced concrete beams without web reinforcement is of the form $(1/6)\sqrt{f'_c}$ MPa.

1.3 Objective

This project aims at developing an analytical model based on the strut-and-tie method which is capable of predicting the modes of failure of reinforced concrete beam strengthened with external reinforcement subjected to third point loading.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

External reinforcement is a tendon or steel plate which is placed on the outside of a member. This method has been widely used for the strengthening and rehabilitation of existing structures. The application of external reinforcement in beam strengthening is quite similar with the application of external prestressing which is a post-tensioning method. However, the above strengthening methods will change the behavior of the structure. Strengthened beam may be more susceptible to shear-type failure, which is different from the mode of failure of the original structure. External reinforcement will help in increasing the flexural strength of the beam but they may not help to increase the shear strength. Therefore, externally reinforced or externally prestressed concrete beam will become more susceptible to shear failure rather than flexural failure.

Flexure is usually considered first in the design of RC beam leading to the size of the section and arrangement of longitudinal reinforcement to resist moment. Basically, the limit placed on the amount of longitudinal reinforcement is to ensure the ductility of the beam, thus giving warning to the occupants before the beam has collapsed. Only then the design for shear reinforcement is carried out. This is in contrast with the nature of flexural failure. For this reason, the amount of shear reinforcement provided must equal or exceed the flexural strength at all sections in the beam. However, shear failure varies widely depending on the dimension, geometry, loading and properties of the member. Thus, there is no specific way for the design for shear.

2.2 Shear Strength of External Prestressing Beams

External prestressing is a post-tensioning method in which prestressing tendons are placed on the outside the concrete section and the prestressing force is transferred to the member through end anchorages, deviators, and saddles. According to Tan (1999), external prestressing offers several advantages such as: 1) the ease in concreting and hence better concrete quality; 2) the use of narrow webs which leads to substantial economic savings; 3) rapidity in construction; 4) the possibility of monitoring and replacement of tendons, as a result, it has been increasingly used in the construction of bridges and also one of the common methods for strengthening and rehabilitation of existing structures.

A research was carried out by Tan and Ng (1998) to study the effect of shear in externally prestressed beams. 7 T-beams, post-tensioned with straight tendons, were tested to failure to study the effect of concrete strength, shear reinforcement, and shear span on the failure mode of externally prestressed beams using strut-and-tie method. Beams were fabricated with a deviator at mid span and tested under simply supported conditions. Each beam was subjected to equal concentrated loads at third points except one, which had a concentrated load at the mid span. The effect of shear in externally prestressed beams was studied by comparing test result on curvatures, steel stresses, deflection, ultimate strength and mode of failure of beam with same test parameter.

Their study concludes that, with decreasing strength in the concrete or reducing the shear reinforcement will lead to shear-type failure. Lowering external tendon stress at ultimate would also reduce the ultimate strength of beams. Therefore, external prestressing contributes a lot in improving the strength of the beam.

The table 2.1 below shows the experimental and theoretical predictions of the beam strength obtained from the study of "effect of shear in externally prestressed beams" by Tan & Ng (1998).

Table 2.1 Results obtained by Tan & Ng (1998)

Beam	Utimate moment Mu KNm		Mu_{exp}/Mu_{theo}
	Experimental	Theoretiacal	
ST-1	97.0	107.7	0.9
ST-2	93.6	99.9	0.9
ST-2C	90.7	94.7	1.0
ST-2C+	81.9	75.3	1.1
ST-2S	89.0	72.0	1.2
ST-2P	99.2	101.6	1.0
ST-3	94.2	97.7	1.0

The theoretical predictions were obtained from a strut-and-tie model. As shown in table 2.1, the theoretical results agree with the experimental results well. In addition, strut-and-tie method also predicts test results of beams tested by Bouafia (1991) very well. It was concluded that the strut-and-tie model could accurately predict the ultimate strength and failure mode of the externally prestressed beams under point loads. Therefore, strut-and-tie model should be able to predict well the shear strength of reinforced concrete beam strengthened with external steel plate.

2.3 Beam Strengthening Using Fiber-reinforced plastic (FRP)

Composite materials are those that consist of reinforcement bonded to a matrix with distinct interfaces between them. Both the reinforcement and matrix retain their physical and chemical identities to produce a combination property that can neither be achieved with either of the constituents acting alone.

Carbon fibers, aramid fibers, glass fibers or vinylon fibers encapsulated in epoxy resin, vinylester resin or other inorganic matrices are used to develop FRP reinforcement. Therefore, continuous fibers will produce desired engineering properties such as high strength, high modulus, high ductility and high resistance against corrosive agents, weathering effects and fire; while non-magnetic properties are ease of transporting, cutting, fabricating and placing of reinforcement. Due to its lightweight, high strength and flexibility in construction, FRP reinforcement is increasingly being used in the retrofitting and repair of structural members. For example, a carbon fibre is bonded with resin to the underside of a reinforced concrete slab to improve the flexural strength and reduce deflection due to cracking.

According to Tan (1999), the fist application of FRP reinforcement was in bridges. Thee bridge using glass FRP tendons were constructed in Germany. The Lunensach-

Gasses Bridge in 1980, the Ulenberg-Strasse Bridge built in Dusseldorf in 1986 and Adolf-Kiepert pedestrian bridge constructed in Berlin in 1989. A post-tensioned concrete highway bridge over the Bachi River in Kitakyusyu, Japan using carbon fiber reinforced plastics (CFRP) was erected in 1989. In Japan, concrete grips are often used on slopes of highway cuts with the grips openings used for vegetation growth. FRP materials are particularly effective in this application when corrosion of wire mesh is concern in places such as hot spring areas. FRP products are also beginning to be used as soil reinforcing material, making tall and steeply sloped embankments possible.

According to the result from Civil and Environmental Engineering, University of Delaware (1999) on a research for a series of 12-reinforced concrete T-beams which was tested to study the effectiveness of shear strengthening using externally applied composite fabrics. Composite fabrics of E-glass, graphite, and Kevlar were bound to the web of the T-beams using a two-component epoxy. The beams were tested and the performances of the eight beams with external shear reinforcement were compared to results of control beams without external reinforcement. Increases in ultimate strength of 55 to 150 percent were achieved for the externally reinforced beam. The composite reinforcement led to an increase in flexural stiffness ranging from 103 to 178 percent, and increases in ultimate beam capacity ranging from 158 to 292 percent, over that of control beams having no external reinforcement. Failures of the composite-reinforced beams were initiated by either tensile failure of the composite or shear failure of the concrete.

CHAPTER 3

METHODOLOGY

3.1 Strut-and tie method

Several studies had been carried out to study the shear behavior of reinforced concrete beam. Rittler (1899) was the first person to propose a simple truss model for shear with diagonals inclined at 45° deg (Fig.3.1). Tan and Naaman (1993) continued the research further on a model based on the strut-tie method. This method was proposed to predict the strength of simply supported, externally prestressed or non-prestressed concrete beams subjected to a mid span concentrated load. Strut-and-tie method or generally known as truss model had been found to be a useful tool in explaining relations between loads, reaction, and internal forces present in concrete and reinforcement. The model defines a safe domain (fig.3.2) within which the beam would not collapse or fail under the applied load. It predicts four possible models of failure; which may be classified into shear-type failure and flexural-type failure.

Shear-type failure of the beam is due to:

1. Crushing of the diagonal compressive concrete strut.
2. Yielding of stirrups or known as yielding of the web reinforcement.

Flexural-type failure is due to:

1. Yielding of the internal longitudinal reinforcement.

2. Yielding of the external plate or tendons.

In this study, a model based on the strut-and-tie method is used to investigate the effect of external reinforcement in concrete beam on the mode of failure of simply supported beams subjected to a third-point loading.